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NASA TECHNICAL TRANSLATION NASA TT F-15,475

MECHANISM OF THE INHIBITED FAILURE OF PLASTIC TITANIUM ALLOYS

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(NASA-TT-F-15475) MECHANISM OF THE INHIBITED FAILURE OF PLASTIC TITANIUM ALLOYS (Kanner (Leo) Associates) 11 p HC $4.00 CSCL 11F

N74-31001

Unclas

G3/17 45886

Translation of "Mekhanizm zamedlennogo razrusheniya plastichnykh splavov titana," Novyy konstruktsionnyy material -- Titan (A New Construction Material -- Titanium), Edited by I.I. Kornilov and N.G. Boriskina, Moscow, "Nauka" Press, 1972, pp. 97-100

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 AUGUST 1974

STANDARD TITLE PAGE

1. Report No. NASA TT F-15, 475	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle MECHANISM OF THE INHIBITED FAILURE OF PLASTIC TITANIUM ALLOYS		5. Report Date August 1974
		6. Performing Organization Code
7. Author(s) V.N. Meshcheryakov and M.Kh. Shorshorov		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates, P.O. Box 5187 Redwood City, California 94063		11. Contract or Grant No. NASw-2481
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, WASHINGTON, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Mekhanizm zamedlennogo razrusheniya plastichnykh splavov titana," Novyy konstruktsionnyy material -- Titan (A New Construction Material -- Titanium), Edited by I.I. Kornilov and N.G. Boriskina, Moscow, "Nauka" Press, 1972, pp. 97-100.

16. Abstract

The mechanism for the inhibited failure of plastic titanium alloys was investigated, and it was shown that Gilman and Rozhanskiy models should be used when research is done into cracks which form in metal with a hexagonal close packed lattice. The total deformation, when stable submicrocracks occur, when testing specimens for inhibited failure, in value, is less than when these specimens are tested for static expansion.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 8 11	22. Price

NASA-HQ

MECHANISM OF THE INHIBITED FAILURE OF PLASTIC TITANIUM ALLOYS

V.N. Meshcheryakov and M.Kh. Shorshorov

Recently the mechanism of the inhibited failure and formation /97* of cold cracks of plastic titanium alloys has been examined with respect to modern dislocation models by Ziner-Stroh, Gilman and Rozhanskiy, Hall and others. The dislocation mechanism for the formation of submicrocracks also gives basis for the existing concept of the effect of hydrogen on the brittleness of metals, since it was not clear how hydrogen could be precipitated from a solid solution without the presence of prepared nuclei of a definite value.

Research into the failure rate of titanium alloys when testing their resistance to inhibited failure was conducted according to a method suggested by I.A. Oding and Yu.P. Liberov [1],which consists of formulating the dependence of the cross-section area of the specimen on the elongation during deformation by static expansion. The basis of this method was determining the value of plastic deformation, during which contraction of the cross section of the specimen begins to fall behind the elongation. This value of deformation, as was determined by electron microscopic and other research, causes the formation of submicrocracks in metal. An estimation of the failure rate was carried out during static deformation by expansion, and also when testing for resistance to inhibited failure, that is, during prolonged aging under a constant load. In both cases, one and the same specimen was used -- a specimen for testing titanium alloys for resistance to inhibited failure by the IMYeT-4 method [2].

The principles of failure rate during static expansion and inhibited failure are qualitatively similar to those observed

*Numbers in the margin indicate pagination in the foreign text.

for pure metals [1, 3]. The only difference is the deformation values, at which the first discontinuity of the curve occurs. Figure 1, as an example, shows the results of tests on the change of cross-section area of metal specimens near the seam area of Ti-Al-V alloys, depending on the total elongation during static expansion and inhibited failure.

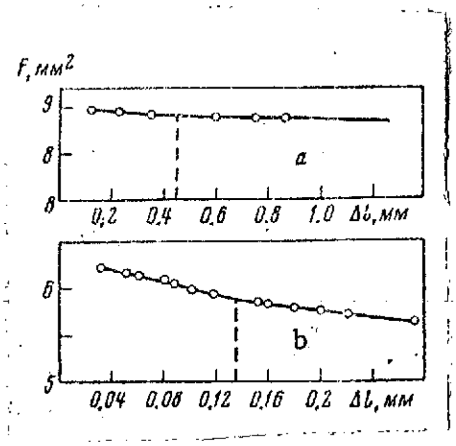

Fig. 1. The dependence of the cross-section area on the total elongation when testing Ti-Al-V alloy specimens for static expansion (a) and inhibited failure (b).

The increase in /98
vanadium content in the Ti-Al-V alloys in ranges of 1.3-3.36% during static expansion, both when testing specimens from the basic metal, and a metal near the seam area, has little effect on the degree of deformation at which the first submicro-cracks are formed. The total deformation when testing specimens from the basic metal is: for the VT6S alloy, 0.5-0.52 mm; for a titanium alloy with 4.55% Al and 2.7% V, 0.4 mm; and for an alloy with 1.3% V, 0.4-0.42 mm. These values for a metal in the seam area are, for the VT6S alloy, 0.5 mm, for an alloy with 2.7% V, 0.42-0.45 mm, and for an alloy with 1.3% V, 0.4-0.42 mm. The total deformation for the VT6S alloy, for the basic metal, and for the metal in the seam area, is higher than for an alloy with a vanadium content of 2.7 and 1.3%, in spite of the fact that the VT6S alloy is considerably harder than the alloys mentioned above. Apparently, this can be explained by the sufficiently high level of plasticity of this alloy during testing for static expansion. In this case, the plasticity characteristics are the same or somewhat higher than the plasticity values of alloys with a decreased content of vanadium.

An approximate calculation, made according to equation [4] which links the applied tensile stress, capable of forming a submicrocrack with the grain diameter, showed that the conformity of theoretical and experimental stress values was only satisfactory for a metal near the seam, and they varied considerably for the basic metal. This is caused not only by a more accurate estimation of grain size for recrystallized metal near the seam area, in comparison with the basic metal, but with specific deformation conditions occurring in alloys with a textured structure. A comparative calculation such as this is completely competent, since the alloys investigated differed little in content and were of similar structure. The calculated length of the crack according to equation $l = 2G\gamma/\pi(1 - \nu)\sigma_p^2$ [5], as was done in work [3], showed that the theoretical values coincide well with the experimental ones. Results of processing the theoretical and experimental information are set out in a table.

THEORETICAL AND EXPERIMENTAL VALUES FOR THE LENGTH OF SUBMICROCRACKS AND STRESSES CAUSING THE APPEARANCE OF THESE SUBMICROCRACKS IN STATIC EXPANSION OF Ti-Al-V ALLOYS.

Alloy Composition, %	State	$d \cdot 10^2$, mm	σ, kgf/mm^2		l, mm	
			Theor.	Exp.	Theor.	Exp.
VT6S	Basic metal	1.76	40	20	0.0015	0.0015—0.003
	Area near seam	6.7	20.5	17	0.0024	0.0026—0.0058
Ti — 4.55 Al — 2.7 V	Basic metal	1.76	40	21	0.00135	0.0012—0.0035
	Area near seam	6.7	20.5	20	—	—
Ti — 4.45 Al — 1.3 V	Basic metal	1.17	49	29	0.00064	0.0006—0.00132
	Area near seam	5.5	23	38	—	—

Note: $\gamma = 0.1\ Gb$, where $G = 4500$ kgf/mm^2, $b = 2.95 \cdot 10^{-8}$ cm; $\nu = 0.36$.

The total deformation of specimens tested for inhibited failure has values less than when testing for static expansion. In this case, the total elongation, like the relative reduction of specimens before failure, both in the basic metal and in metal near the seam of the VT6S alloy, is lower than for an alloy with a reduced vanadium content. An increase in the vanadium content or a reduction of the alloy's plasticity should cause an even greater reduction of the total deformation at which submicrocracks form.

As was stated in work [6], the specific energy of ultimate deformation A_{p_0} of a brittle material is considerably less than the corresponding value of A_{p_0} for a more plastic material. /99
This ratio also takes place between absorbed energy necessary for the formation of submicrocracks and microcracks ($A_{G_{sub}}$ and $A_{p_{mic}}$). Therefore, the failure of low-plastic alloys, normally takes place during a shorter time and at lower stresses. In these conditions, the main value is assumed by factors which cause the light spread of a crack: the reduction of surface energy of the crack formed, due to the presence of adsorbed gas or a directed influx of vacancies, and also the development and level of plastic deformation in front of the developing crack. Here, one must take into account that the further development of a crack is only observed when the length of the crack reaches a definite value. When testing specimens for inhibited failure, the increase of applied stress does not significantly affect the value of total deformation, nor the formation time of submicrocracks, whereas the length of spread of a crack is sharply reduced with the increase of applied stress. Here, it is assumed that the plastic deformation near the end of a crack is insignificant, if the development of a crack occurs sufficiently quickly.

Microstructure analysis, carried out with a light microscope, showed that failure is always preceded by plastic deformation.

Normally, microcracks are found perpendicular to the applied stress. An electron microscope detected submicrocracks with a width of 300-900 Å and a length of 0.0006-0.006 mm on the non-corroded surface of deformed specimens (Fig. 2). As the amount of deformation increases, the number and size of cracks formed also increases. Mainly, all these cracks form in slip bands according to dislocation models examined earlier [2] by Gilman [7, 8] and V. N. Rozhanskiy [9, 10].

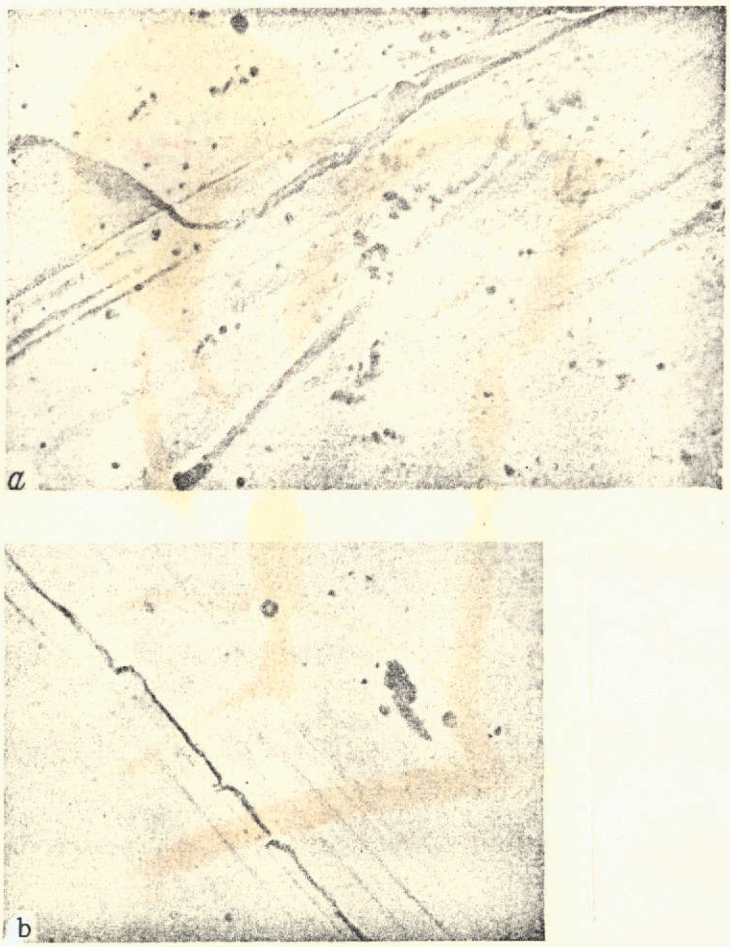

Fig. 2. Microscopic cracks in alloys with medium and low yield limits. a - VT6S, 7700x; b - a Ti-Al-Zr alloy, 4200x.

By using a special method for preparing specimens (polished and non-corroded specimens were welded in a vacuum or in a chamber with a controlled atmosphere), submicroscopic cracks were detected on the area near the seam of welded joints of plastic titanium alloys, the width and length of which corresponded to cracks formed in the deformation process of specimens during static expansion or during testing for inhibited /100 failure. Light

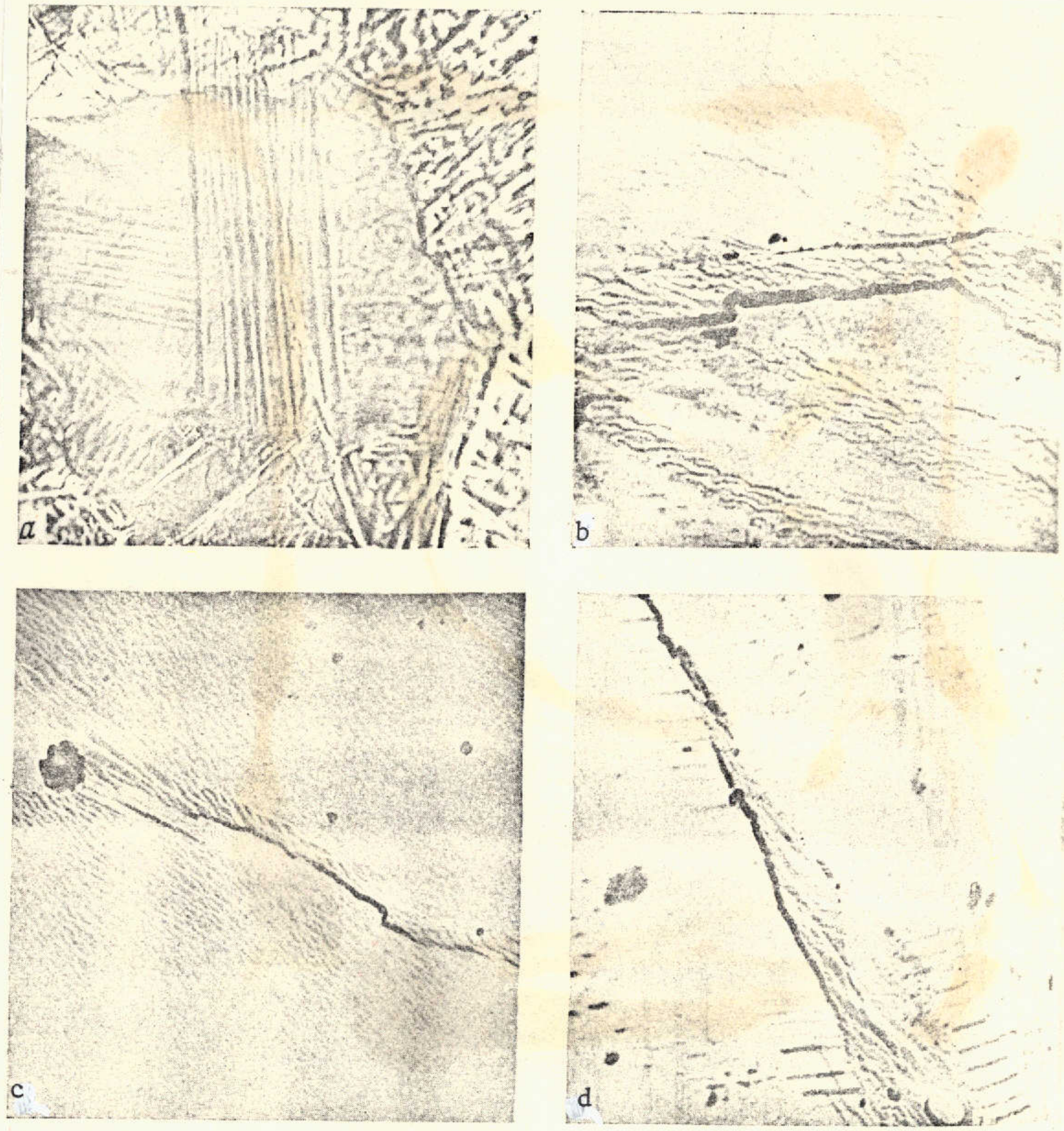

Fig. 3. The microstructure of the noncorroded surface of specimens after welding (area near the seam). a - Ti-Al-Zr alloy, 400x; b - VT6S, 7700x; c - Ti-Al-Zr alloy, 4800x; d - OT4-1, 4800x.

microscope research showed that in the area near the seam of different titanium alloys, apart from a clearly defined polymorphic transformation, there was a deformation in the form of individual slip bands which transfer from one grain to the next one, or without completely changing the angle of inclination, or changing it to a small angle to previously active slip bands, create the possibility for a light slip when applying active loading or dislocation movement from residual welding stresses (Fig. 3, a).

The formation of cracks independent of the mechanism of their formation is linked with the moment when coarse slip bands occur, that is, the cracks form when the metal reaches a critical dislocation density in local volume [11]. The greatest dislocation density is formed in slip bands where the shift is slowed down by some obstacle (grain boundaries, twins, etc.). The majority of cracks detected in the area near the seam of welded joints are in slip bands near obstacles in the form of grain boundaries of α'-phase fragments (Fig. 3, b÷d). Cracks which form after welding have a width of 160-900 Å and a length of 0.0003-0.006 mm.

Conclusions

1. When analyzing the formation mechanism of cracks in plastic titanium alloys, one must begin by using modern dislocation models. The most practical are those models showing the formation of cracks in metals with a hexagonal close packed lattice, the Gilman-Rozhanskiy models.

2. Principles of failure rate of titanium alloys during static expansion and inhibited failure are qualitatively similar to those for pure metals. Both in static expansion and when testing for inhibited failure, the first submicrocracks appear long before the final failure of specimens. The total deformation,

at which stable submicrocracks appear when testing specimens for inhibited failure, in value, is considerably less than when testing these same specimens for static expansion.

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